SETTLEMENT OF A GROUP OF STONE COLUMNS IN SOFT SOIL

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ABSTRACT

A number of theoretical methods have been developed over the years to calculate the amount settlement of the soil reinforced with group of stone columns. The results deduced from these methods sometimes show large disagreement with the experimental observations. The reason of this divergence might be due to the fact that many of the previous methods assumed the deform shape of the columns which is different with the actual case. A new method to calculate settlement of the ground reinforced with group of stone columns is presented in this paper which overcomes the restrictions made by previous theories. This method is based on results deduced from numerical modeling. Results obtained from the model are validated.

Key Words: Stone columns, group, settlement, soft soil, prediction, geo-materials

RÉSUMÉ

A number of theoretical methods have been developed over the years to calculate the amount settlement of the soil reinforced with group of stone columns. The results deduced from these methods sometimes show large disagreement with the experimental observations. The reason of this divergence might be due to the fact that many of the previous methods assumed the deform shape of the columns which is different with the actual case. A new method to calculate settlement of the ground reinforced with group of stone columns is presented in this paper which overcomes the restrictions made by previous theories. This method is based on results deduced from numerical modeling. Results obtained from the model are validated.

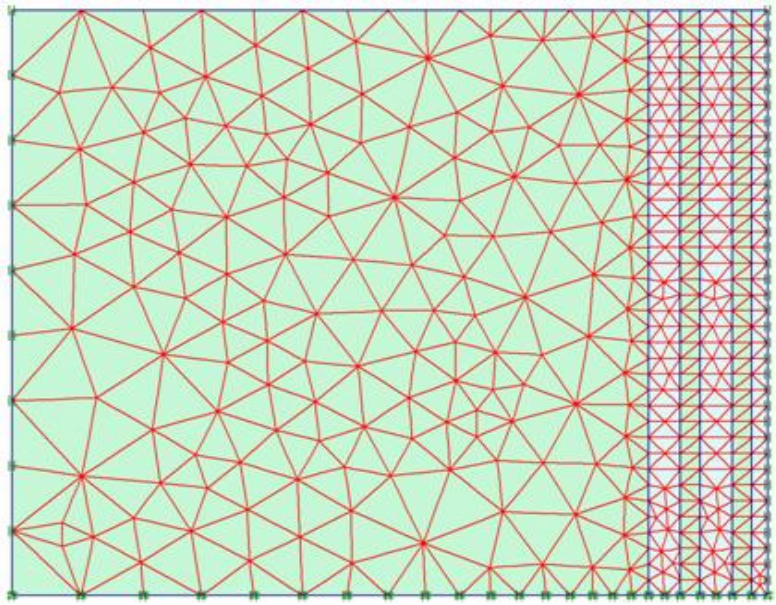
Mots Clés: Colonnes ballastées, groupe, tassement, sol mou, prédiction, géo-matériaux

1- INTRODUCTION

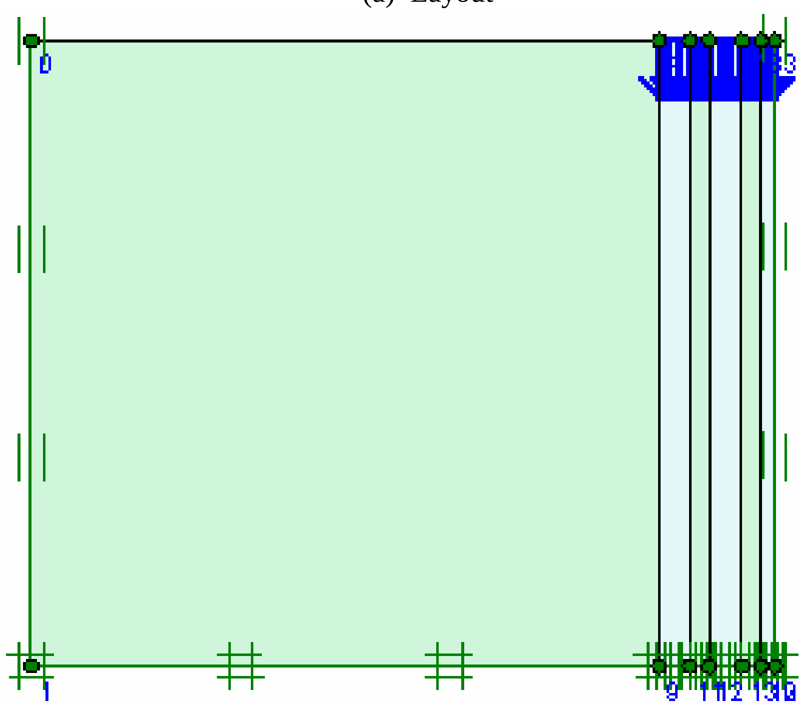
Stone columns method is an effective ground improvement technique which is used over the years to increase bearing capacity and reduce settlement of the soft soil foundations. Calculation method for settlement of stone columns was first presented by Greenwood [1]. He developed a chart of this purpose which was based on experimental work. In 1974 Hughes and Withers [2] observed that a single stone column bulges as the result of applying load and collapse due to bulging failure. They declared that group of stone columns can have the same collapse form. Priebe [3] developed a theoretical model based on settlement of single stone column. He assumed that the deform behaviour of group of stone columns is same as the single one and developed his theory for single stone column by considering that it can be applied to group of columns as well. Later Balaam and Booker [4], Goughnour and Bayuk [5], Barksdale and Bachus [6], Poorooshasb and Meyerhof [7] and Poorooshasb et al [8] developed theoretical and numerical models based on the same assumption first suggested by Hughes and Withers [2]. In 1998 Lee and Pande [9] developed a method based on homogenization approximation where it was assumed that granular material scattered homogenously throughout the soil and finite element code was written to solve the problem. In 1995 Hu [10] criticized the assumption made by Hughes and Withers [2] and others and declared that group of stone columns perform a deform shape as the result of loading which is quite different from single columns. He concluded that group of stone columns fail due to shear. Wehr [11], Wood et al [12], SeokBae and Shin [13] and Etezad et al [14] reported the same observation. These researches suggested that a theoretical method to calculate the settlement of stone columns should be developed based on the performance of group of stone columns so that the accurate deform shape of the columns could be taken into consideration. A numerical model utilizing finite elements technique is developed in this paper which takes into account this effect.

2- NUMERICAL MODEL

In order to calculate settlement of reinforced ground, numerical model was developed using PLAXIS V8 finite element program. The boundary of the numerical model was established in the way that both horizontal and vertical stress confinement within the soil boundary was eliminated. Fixed support boundaries were considered at the bottom of the model and hinged supports were used on both horizontal directions. This arrangement represented a real case in the field. Square arrangement of stone columns was considered which can be simplified as the plane-strain form. In this model, a plane-strain condition with 4^{th} order 15-node triangular elements was applied. Medium dense form of mesh generation was utilized as the global coarseness of the model. In the area of reinforced ground meshes were refined in order to have more accurate result. Mohr-Coulomb constitutive law was used both for granular and soft soil materials. This study is limited to long stone columns under the raft foundation. Half of the reinforced soil was analyzed in all the conducted tests only due to symmetry of the system. (Figure 1),



(a) Layout



(b Mesh generation)

Figure 21. (a) Layout and (b) Mesh generation of a typical preformed test.

Table 1 illustrates the range of soil and geometry properties which were used in the numerical model.

Table 1. Data used in the numerical model

	Site conditions	Range of values
Clay	Angle of shearing resistance Cohesion Dry unit weight Modulus of elasticity Poisson's ratio	5˚-25˚ 3-15 kN/m^2 10-16 kN/m^3 1000–15'000 kN/m^2 0.15-.45
Granular material	Angle of shearing resistance Dry unit weight Modulus of elasticity Poisson's ratio Angle of dilatancy	30˚ to 45˚ 14-21 kN/m^3 30'000– 300'000 kN/m^2 0.15-0.45 $\psi = \varphi$-30^o (Bolton 1986)
Geometry condition	Area replacement ratio (A_s) Diameter of stone columns	10%, 20% , 30% 0.6 - 1.2 m

The model is validated utilizing the experimental work conducted by Hu [10]. Table 2 repents the comparison between experimental and numerical results were good agreement between the two was achieved.

Table 2. Validation of the numerical model (After Etezad et al [15])

Test number	A_s	C_u (kPa)	Column length (mm)	Hu's experiments (kPa)	Present numerical model (kPa)
TS05	30	10.5	100	79	72
TS17	24	14	160	71	64
TS04	24	16.5	150	77	72
TS10	30	11.5	100	75	69

In order to develop the model a uniform settlement was applied to the reinforced ground and load corresponding to the displacement was determined at the end of calculation. Lots of trials had been preformed for different soil and geometry conditions. All the characteristics which were believed to have influence in the final results were examined. Figures 2 and 3 represents the effect of column diameter and Poisson ratio on the behaviour of reinforce ground. Little discrepancy of the results was observed.

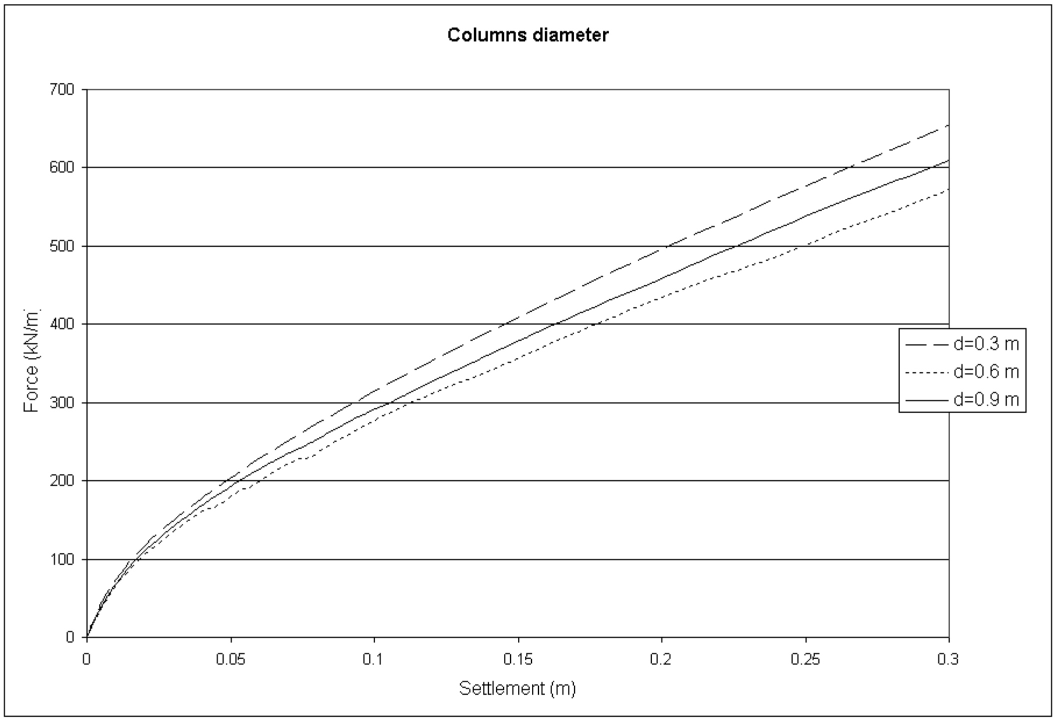


Figure 2. Effect of column diameter on load displacement curve.

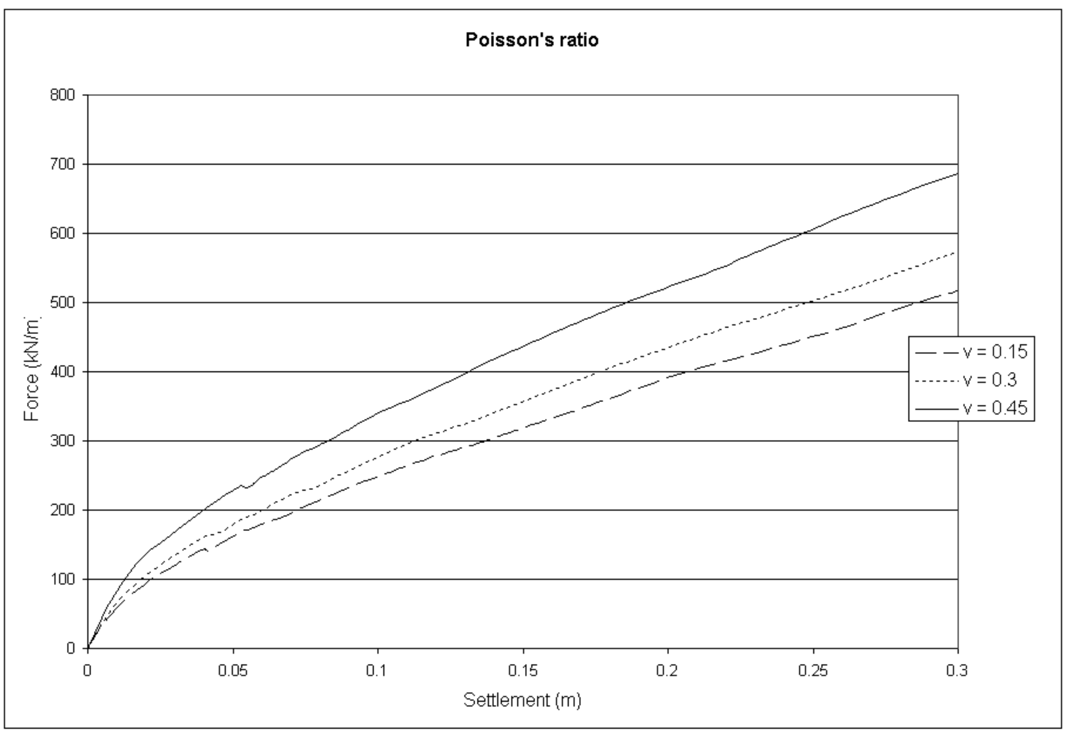


Figure 3. Effect of Poisson ratio on load displacement curve.

Figures 4 and 5 show the effect of cohesion of soft soil and angle of dilatancy of granular material on load displacement curve. Not noticeable difference in trials was observed again.

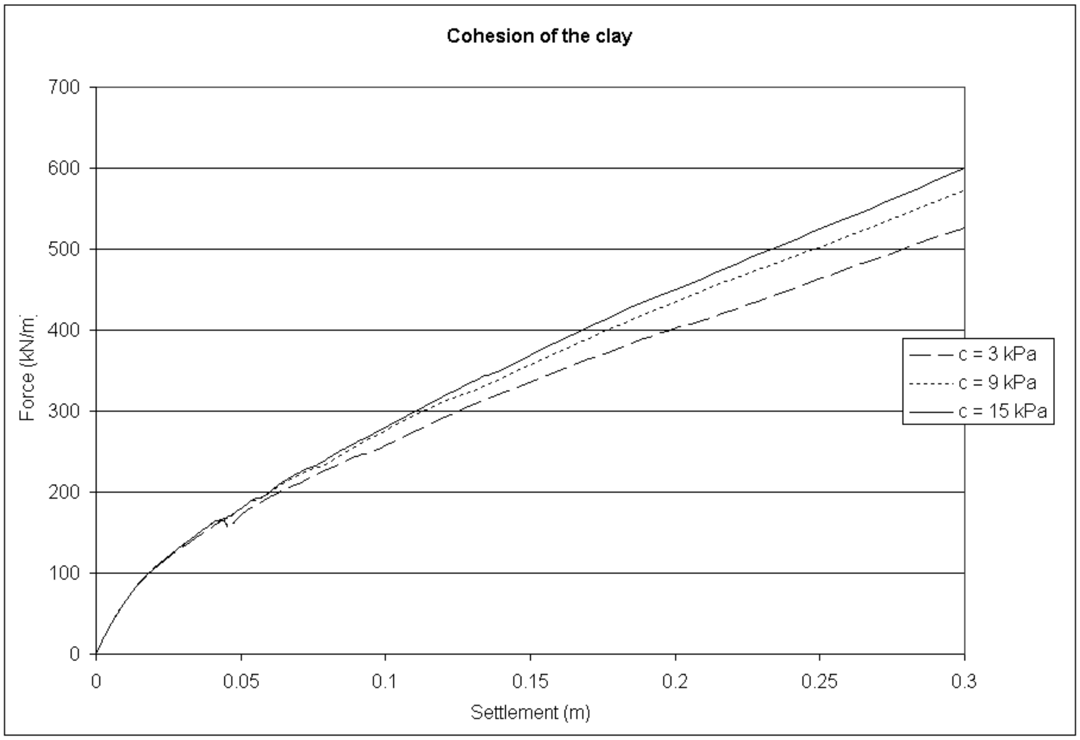


Figure 4. Effect of cohesion of soft soil on load displacement curve.

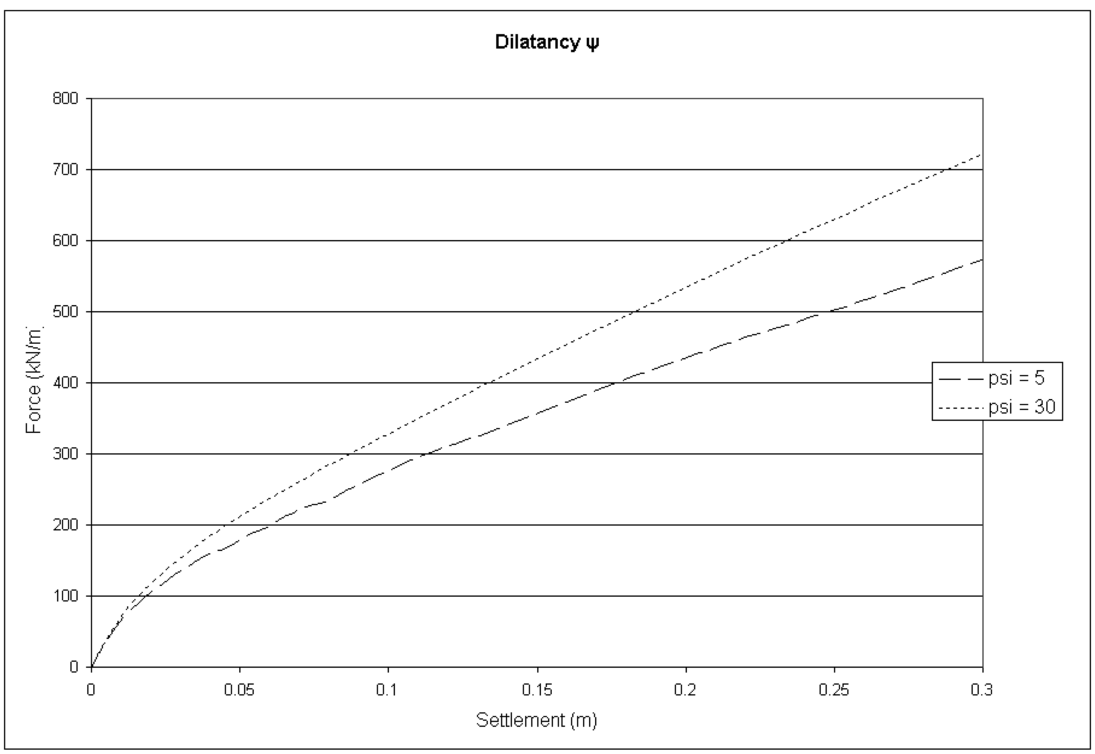


Figure 5. Effect of delitancy of stons on load displacement curve.

Based on observation of Etezad et al [14] research and this study it can be concluded that the two parameter of angle of shearing resistance of soil materials and spacing between the columns have major influence on the ground reinforced with the group of columns. Therefore the final charts were developed based on these parameters.

3- RESULTS

Utilizing results obtained from the trials, graphs were developed to calculate the settlement of the reinforced ground. Area ratio was defined in this research as

$$A_s = \frac{A_{col}}{A} \qquad (1)$$

Where A_{col} and A represents the area of stone columns and area of unreinforced soil under the foundation respectively.

Using the area ratio angle of shearing resistance of soft soil and stone settlement of the composite soil can be calculated. For each test, Chin [16] extrapolation was used. Settlement of the composite soil was written as:

$$\frac{S}{p} = a.S + 0.1.b \qquad (2)$$

Where a and b for can be calculated from the Figures 6 and 7. S and p are settlement and foundation loading pressure respectively.

Having φ_{stone}, φ_{clay} and A_s, the values of a and b can be obtained. Consequently for the required foundation loading pressure by utilising Equation 2, settlement of the ground reinforced with group of stone columns can be obtained.

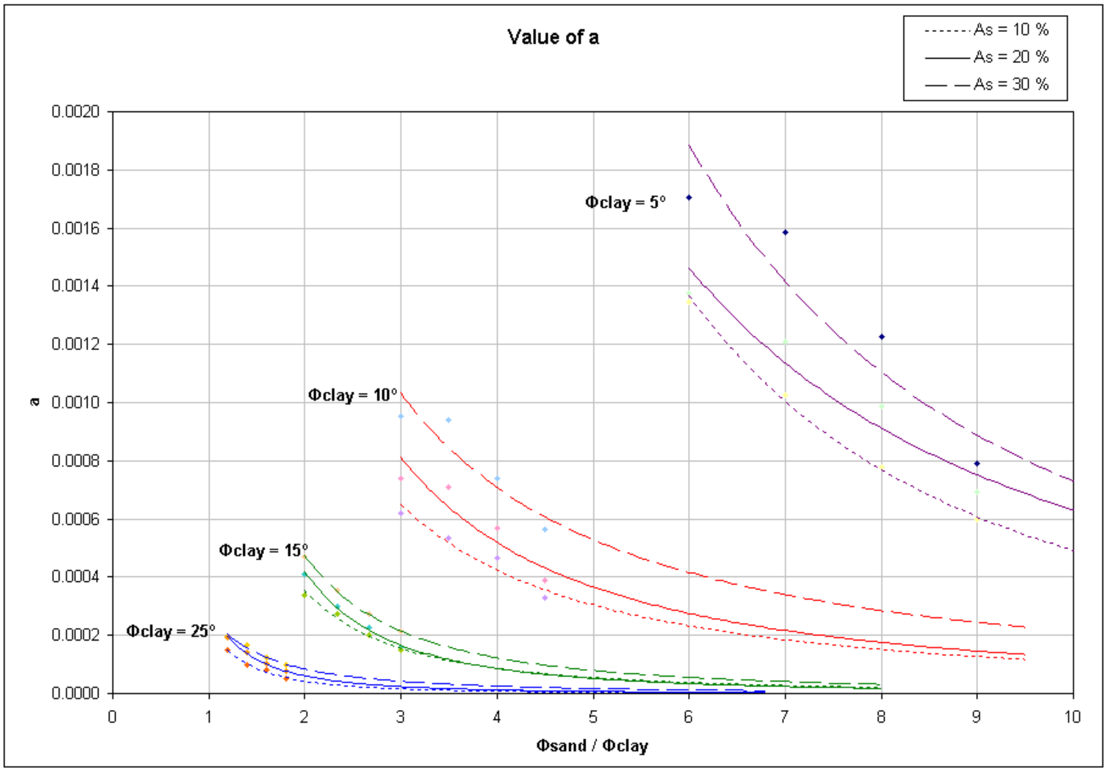


Figure 6. Value of *a* for prediction of settlement

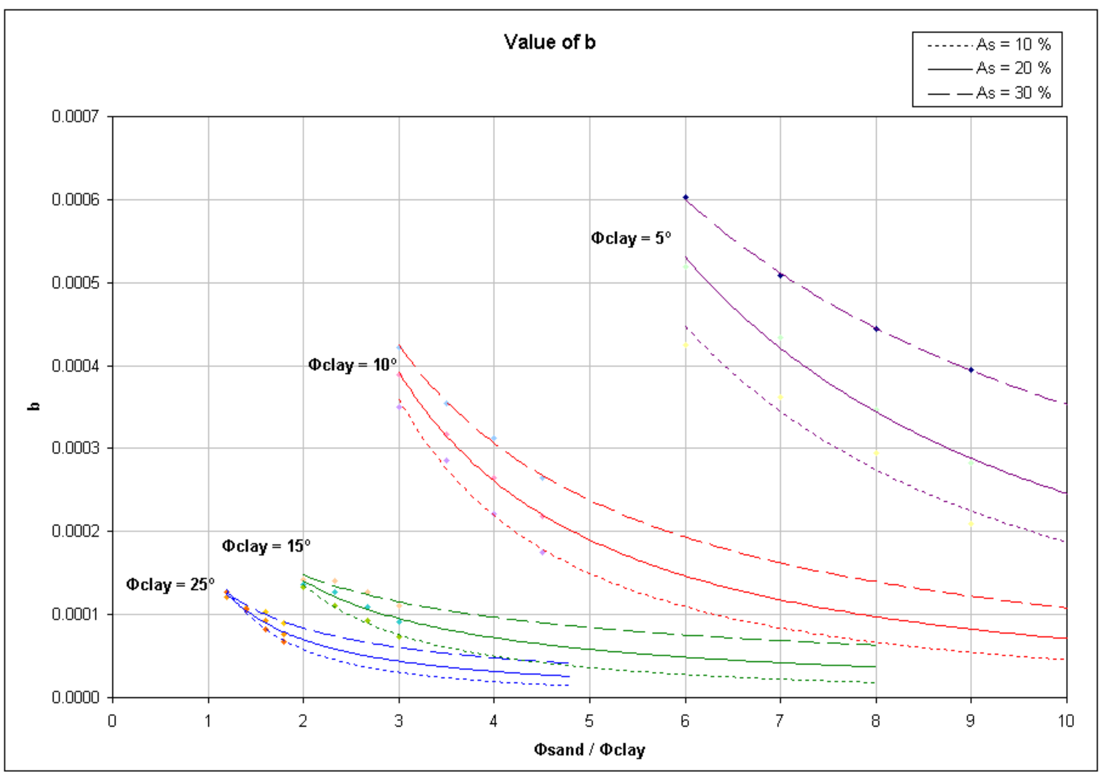


Figure 7. Value of *b* for prediction of settlement

Table 3 shows comparison between result from this paper and the laboratory experiment conducted by Hu [10]. Good agreement between the two was observed.

Test No.	φ_{stone}	φ_{clay}	A_s	p (kN/m^2)	Settlement (mm)	
					Numerical model	Observed
TS05	30	23	30 %	70	10	12
TS09	35	25	30 %	85	14	17

4- CONCLUSION

Stone columns have been well recognized as a cost effective and environmental friendly ground improvement technique. In the literature, several theories and empirical formulas can be found to predict the amount settlement of reinforced ground. The results produced by these methods are widely scattered. This may be explained by the fact that these methods were developed based on the unit cell concept of individual columns, whereas they are interacting with each others and act as a group.

This paper presents a method to predict the settlement of a group of stone columns. The theory is based on the results of a numerical model developed for this purpose and the experimental results available in the literature. The model utilizes “PLAXIS” and is based on two dimensional finite element technique. Parametric study was performed on the parameters believed to govern the settlement of the group. Based on the results obtained from this study, design theory and design charts are developed for practical use. Results obtained from the model are compared with the available experimental data, where good agreement was noted.

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